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Throughput Performance of WLANs Operating at 5GHz Based on Link Simulations with Real and Statistical Channels

Angela Doufexi[1], Simon Armour[1], Peter Karlsson[2], Andrew Nix[1], David Bull[1]
[1]Centre for Communications Research, University of Bristol, U.K.
[2] Telia Research AB, Malmoe, Sweden
E-mail: A.Doufexi@bristol.ac.uk

Abstract

At present, Wireless Local Area Networks (WLANs) supporting broadband multimedia communication are being developed and standardized in the 5 GHz band. Two such standards are HIPERLAN/2, defined by ETSI BRAN, and the IEEE 802.11a. This paper presents the throughput performances of the two standards based on link simulations with real and statistical channels. Physical layer performance results are presented for real channel measurements and the impact of sectorised antennas at the access point is given for HIPERLAN/2.

1. Introduction

HIPERLAN/2 [1,2] and IEEE 802.11a [3,4] are two WLANs standards that will operate in the 5GHz band and provide data rates up to 54 Mbps.

The physical layers [1,3] of both standards are very similar and are based on the use of Orthogonal Frequency Division Multiplexing (OFDM). Importantly, the physical layer provides several modes, each with different coding rates and modulation. These are selected by a *link adaptation* scheme. Only minor differences exist between the two physical layers [5-7]. A detailed description of the PHY layers can be found in [5].

The main differences between IEEE 802.11a and HIPERLAN/2 occur in the Medium Access Control (MAC). The IEEE 802.11 standardization group has specified a common MAC mechanism for IEEE 802.11, IEEE 802.11a, and IEEE 802.11b that is based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) [4].

In HIPERLAN/2 the medium access is based on a TDD/TDMA approach using a MAC frame with a period of 2 ms [2]. The control is centralized to an 'Access Point' (AP) which informs the 'Mobile Terminals' (MTs) at which point in time in the MAC frame they are allowed to transmit their data. The HIPERLAN/2 MAC also provides explicit support for the use of "smart" sectorised antennas at the AP.

This paper presents the throughput performances of the two standards based on link simulations with real and statistical channels. In addition, the impact on performance and throughput that results from the use of sectorised antennas in HIPERLAN/2 is investigated.

Section 2 presents the MACs specified by the two standards. The channel models and the real channel measurements are described in Section 3. Performance results are given in Section 4, which show PER and throughput results against carrier-to-noise ratio (C/N) at various channel delay spreads. Section 5 discusses the results and concludes the paper.

2. Medium Access Control (MAC)

2.1 IEEE 802.11 MAC

To access the medium, IEEE 802.11 provides two types of service: asynchronous and contention free [9]. The asynchronous type implements a CSMA/CA MAC protocol, with binary exponential back off, known as the distributed coordination function (DCF). DCF defines a basic access method, and an optional four-way handshaking technique, known as the *request-to-send/clear-to-send* (RTS/CTS) method [9]. The contention free service is provided by the point coordination function (PCF) in order to support time-bounded services. PCF is optional and will not be considered in this work.

A mobile terminal must sense the medium for a specific time interval and if the medium is idle it can start transmitting the packet. Otherwise the transmission is deferred and a backoff process begins, which means that the terminal has to wait for a time interval. Once the backoff time has expired, the terminal can access the medium again [9-11]. Because a collision in a wireless environment is undetectable, a positive acknowledgement is used to notify that a frame has been successfully received. If this acknowledgement is not received the terminal will retransmit the packet.

For IEEE802.11a the basic DCF access mechanism is considered. The transmission cycle consists of the following phases (Figure 1): DIFS (distributed interframe space), Back off, Data Packet Transmission, SIFS (short interframe space), and Acknowledgement (ACK).

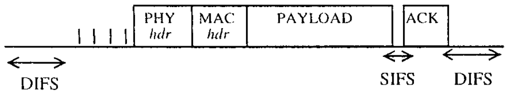

Figure 1: DCF Access Mechanism

The Physical Layer Convergence Procedure (PLCP) maps a MAC PDU into a frame format. Figure 2 shows the format of a complete packet (PPDU) in 802.11a, including the preamble, header and Physical Layer Service Data Unit (PSDU or payload). The header contains information about the length of the payload and the transmission rate. The length field takes a value between 1 and 4095 and specifies the number of bytes in the PSDU.

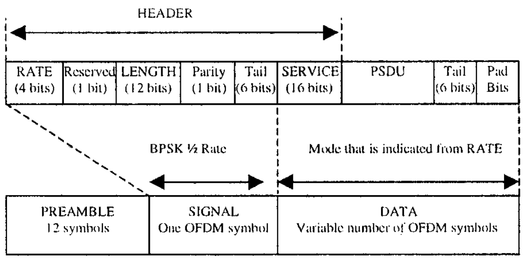

Figure 2: PPDU Frame Format

2.2 HIPERLAN/2 MAC

In HIPERLAN/2 the medium access is based on a TDD/TDMA approach using a MAC frame with a period of 2 ms [2]. The control is centralized to an 'Access Point' (AP) which informs the 'Mobile Terminals' (MTs) at which point in time in the MAC frame they are allowed to transmit their data. Time slots are allocated dynamically depending on the need for transmission resources.

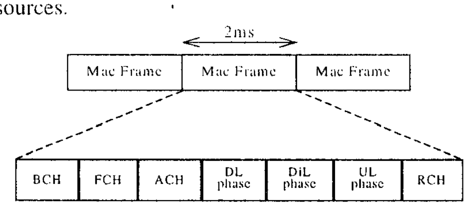

Figure 3:The HIPERLAN/2 MAC Frame

The MAC frame structure (Figure 3) comprises time slots for broadcast control (BCH), frame control (FCH), access feedback control (ACH), and data transmission in downlink (DL), uplink (UL), and directlink (DiL) phases, which are allocated dynamically depending on the need for transmission resources. An MT first has to request capacity (RR) from the AP in order to send data. This is performed in the random access channel (RCH), where contention for the same time slot is allowed [2].

Downlink, uplink and directlink phases consist of two types of PDUs: long PDUs and short PDUs. The long PDUs (Figure 4) have a size of 54 bytes and contain control or user data. The payload is 48 bytes and the remaining bytes are used for the PDU Type, a sequence number (SN) and a cyclic redundancy check (CRC-24). Long PDUs are referred to as the long transport channel (LCH).

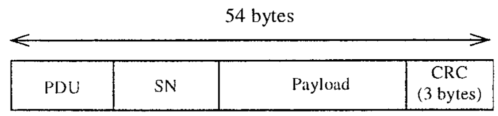

Figure 4: Format of the long PDUs

The HIPERLAN/2 MAC provides explicit support for the use of "smart" sectorised antennas at the AP. This is achieved by transmitting separate BCH, ACH and FCH sequences for each sector employed. Antenna sectorisation improves performance by allowing the link adaptation mechanism to make use of higher modulation modes more frequently. However, the additional BCH, ACH and FCH transmissions represent an additional overhead in the MAC frame. Thus, an effective trade-off of PHY and MAC efficiency is required.

3. Channel Scenarios

Seven different channel scenarios, summarized in Table 1, are considered in this paper. The first scenario is test channel A [13], specified by BRAN as a statistical representation of a typical office environment (omni-directional antenna at the AP and no Line of Sight). The remaining six scenarios are based on channel measurements made in three office environments [14], R1 - R3 with a 60° switched sectorised antenna at the AP. In all cases, the mobile terminal uses an omni-directional antenna. More details about the channels can be found in [14,15].

Table 1: Channel Scenarios

Name	AP Antenna	RMS Delay Spread (ns)	Sector Gain (dB)
A	Omni	50 (Rayleigh)	-
R1O	Omni	18 (Rician)	-
R1S	Sectorised	9 (Rician)	7.25
R2O	Omni	29 (Rayleigh)	-
R2S	Sectorised	24 (Rayleigh)	4.3
R3O	Omni	38 (Rayleigh)	-
R3S	Sectorised	32 (Rayleigh)	3.5

4. Performance Results

The throughput performance of the two WLAN standards has been evaluated in relation to overhead. Sources of overhead are gap time, preamble, header fields for the PHY and MAC layers, and ACK frames.

The measurement of net throughput in WLANs is mostly performed by registration of the time it takes to transfer large files between server PC and wireless clients [12]. The effective net throughput depends on the mode chosen by the wireless station to communicate with its AP together with the overhead for each standard. It should be noted that TCP/IP overheads are not considered in this study.

4.1 IEEE 802.11a Throughput Results

The maximum throughput for the different modes and PSDU sizes was derived based on the parameters of Table 2. It is assumed that only one terminal transmits and one terminal receives (no collisions) and that the medium is never idle [8]. The parameter BPOS (Bytes / OFDM Symbol) depends on the mode [5]. The throughput for each mode depends mainly on the size of the PSDUs (Figure 5) and is given by [8]:

$$\textit{Throughput} = \textit{Payload/Transmission cycle} \quad (1)$$

Table 2: IEEE 802.11a MAC Parameters

Parameter	Duration (μs)
DIFS	34
SIFS	16
Slot time	9
Back-off time [8]	7.5*9=67.5
PLCP Preamble	16
Signal	4
MAC header	4*[34 Bytes/ BPOS]
ACK Packet	20+4*[14 Bytes/ BPOS]
Data Packet	20+4*[(34 + PSDU size) / BPOS]

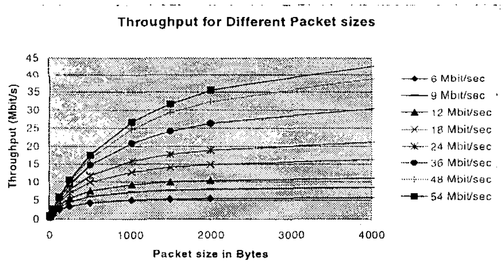

Figure 5: IEEE 802.11a Maximum Throughput for Different PSDU sizes

Figure 6 shows the simulated throughput in IEEE802.11a, based on the maximum throughput results for each mode (Figure 5) and the PER performances of the physical layer [5]. The link adaptation mechanism enables the system to adapt the transmission mode to the radio link quality. The mode with the highest throughput is chosen for each instantaneous C/N value.

The PSDU size was chosen so as to achieve an optimal tradeoff between overhead efficiency and PER performance [5]. IEEE802.11a provides high throughput only with a PSDU size of 1500 bytes or more. If there is an infrastructure with an IEEE802.3 (Ethernet) wired connection to the AP, the maximum payload of the packets becomes 1500 bytes.

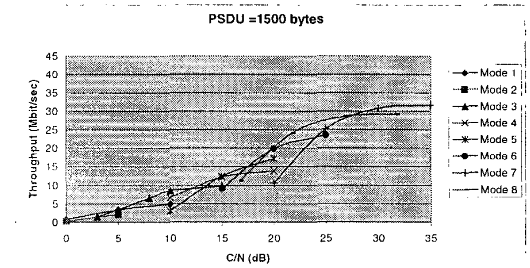

Figure 6: Throughput with Link Adaptation for IEEE 802.11a (Channel model A)

4.2 HIPERLAN/2 Throughput Results

Table 3: HIPERLAN/2 MAC Parameters

Parameter	Duration (μs)
BCH + Preamble	36
FCH	36
ACH	12
RCH + Preamble	28
Downlink Preamble	8
Uplink Preamble	12
SCH PDU (RR)	12
ARQ	12
MAC period	2000

For HIPERLAN/ 2 it was again assumed that transmission occurs between one AP and one MT. From the 54 bytes in the PDU, 48 bytes are allocated for the payload. Hence, there is a small overhead due to *Segmentation and Reassembly (SAR)* to 48-byte packets [2]. Based on the parameters of Table 3 and the PER performances of each mode [5] the throughput for HIPERLAN/2 was calculated (Figure 7).

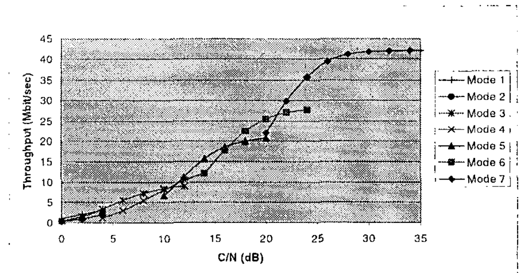

Figure 7: Throughput with Link Adaptation for HIPERLAN/2 (Channel model A)

Based on the results of Sections 4.1 and 4.2, the throughput for the two standards over range can be seen in Figure 8. These results are based on the path loss model and power output values as described in [5].

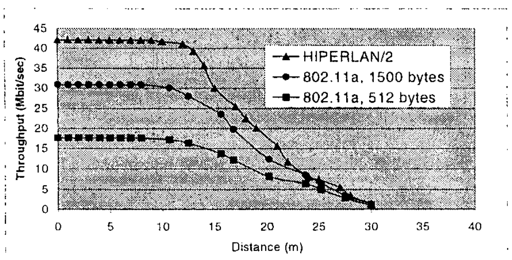

Figure 8: Throughput over range

4.3 Throughput Results with Real Channels

The HIPERLAN/2 MAC provides explicit support for the use of "smart" sectorised antennas at the AP. This is achieved by transmitting separate BCH, ACH and FCH sequences for each sector employed.

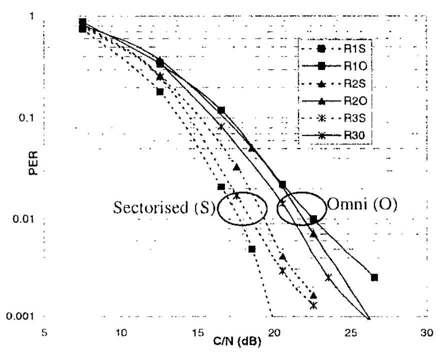

Figure 9: PER for HIPERLAN/2 with Sectorised Antennas (Mode 5)

Figure 9 presents the simulated performance for real channel scenarios R1-R3 for mode 5. These results clearly demonstrate that performance in measured channels R1-R3 is significantly enhanced by sectorisation. In channels with a dominant multipath component (R1), the correct choice of sector reduces the multipath activity and improves the Rician statistics.

The Sector Gain column in Table 1 evaluates the measured antenna gain between the sectorised and omni-directional case as perceived at the receiver. Note: in all three cases the receiver gain is less than the theoretical 7.8dB (dipole) azimuth gain of a 60° sector. This loss is directly related to the fraction of the multipath energy falling outside the main beam of the chosen sector. In the case where the sectorised antenna is used for transmission, its full gain will be realized. However, this gain will be mainly realized as a power saving in both the MT and AP (due to EIRP limits) and as a performance gain resulting from reduced interference.

However, these benefits must be offset against the additional MAC overhead for the separate BCH, ACH and FCH sequences for each sector. Figure 10 shows the maximum throughput of each mode for different numbers of sectors.

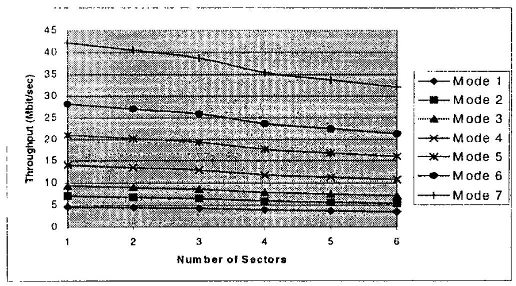

Figure 10: Maximum Throughput for HIPERLAN/2 with Sectorised Antennas

Based on the PER performances of each mode, Figure 11 shows the link throughput for HIPERLAN/2 with sectorised antennas for office environment R1. Similar results were observed for environments R2, R3.

From Figure 11 it can be seen that antenna sectorisation improves link throughput (by up to 10 Mbps) by allowing the link adaptation mechanism to make use of higher modulation modes. Link throughput (*THR=R (1-PER)*) is also increased because of the lower PER of each mode for a specific C/N value (see Figure 9).

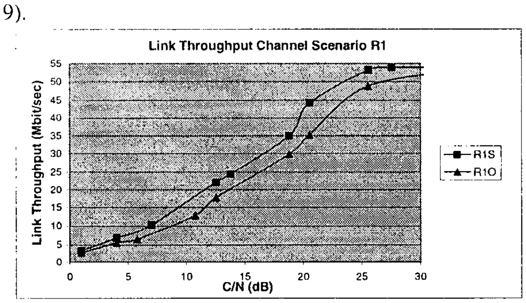

Figure 11: Link Throughput for HIPERLAN/2 with Sectorised Antennas

Combining all the results from Figures 9-11, and Table 1 (antenna gain) the system throughput (including MAC overheads) over range can be seen in Figure 12. It can be seen that the use of sectorised antennas increases the operating range. The throughput is lower for the first few meters due to the additional MAC overhead for the separate BCH, ACH and FCH sequences for each sector. This is due to the fact that mode 7 can be used at this range even with omni antennas.

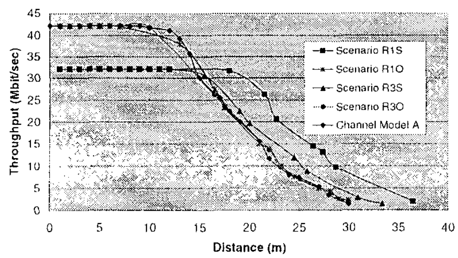

Figure 12: Throughput of HIPERLAN/2 over distance from AP

5. Conclusions

Throughput results with link adaptation have been presented for both HIPERLAN/2 and IEEE 802.11a standards for the case of transmission over channel A.

In IEEE 802.11a, which has variable size packets, results suggest that the PSDU size will have a significant impact on throughput. In order to optimize throughput, a PSDU size of 1500 bytes was chosen. Table 4 shows a comparison of the throughput for 1500 byte long packets (HIPERLAN/2 uses Segmentation and Reassembly).

Table 4:Max.Throughput with 1500 byte Packets

Rate	IEEE 802.11a		HIPERLAN/2	
	Mbit/sec	%	Mbit/sec	%
6	5.38	89	4.68	78
24/27	17.7	74	21.1	78
36	24	66	28.13	78
54	31	57	42.18	78

The higher the data rate the higher the influence of the PSDU size. It can be seen that the relative throughput for 802.11a varies from 57%-89% depending on the mode that has been used. The reason for this is that the time required for SIFS and DIFS is independent of the mode and so it affects the higher data rates more (for the same duration of time, higher rates transmit more data). That is not the case for HIPERLAN/2 where the percentage throughput is not significantly dependent of the mode.

Simulated PER results for real channel scenarios demonstrated that link performance is significantly enhanced by sectorisation. Results showed that antenna sectorisation improves link throughput by allowing the link adaptation mechanism to make use of higher modulation modes. However, these benefits must be offset against the additional MAC overhead.

Throughput results over distance for one AP showed that range can be increased with the use of sectorised antennas at the AP.

When the sectorised antenna is used for transmission, its full 7.8dB gain will be realized. This gain will be mainly realized as a power saving in both the MT and AP (due to EIRP limits) and as a performance gain resulting from reduced interference.

Acknowledgements

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